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Comparison Between Fuel Cell and Hydrogen Engine Fuel Consumption

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Outline

- PSAT Modeling Assumptions
  - Vehicle
  - Fuel Cell System
  - Hydrogen Engine
- Component Sizing
- Simulation Results

Vehicle Assumptions

- Midsize car platform
- Both non-hybrid and hybrid configurations considered
- All vehicles achieve similar performances (0-60mph, grade)
- All vehicles have same amount of onboard H2 (5kg)
- Component uncertainties taken into account
- UDDS and HWFET drive cycles considered
- Ratios based on fuel economy gasoline equivalent using 2008 EPA corrections

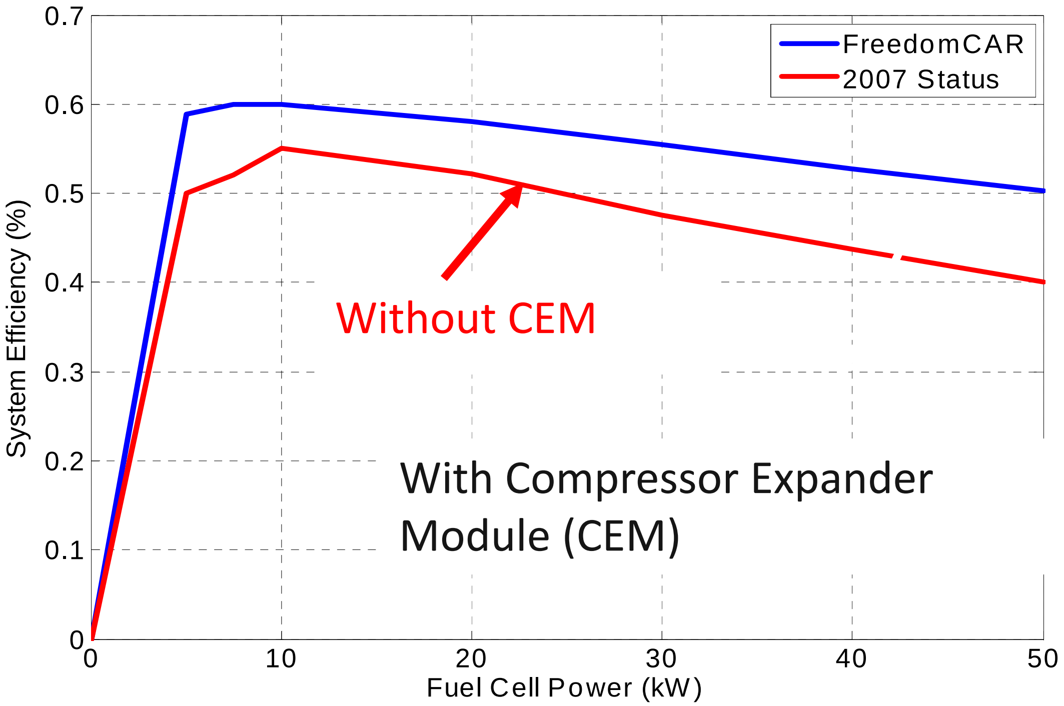
Parameter	**Unit**	**Midsize Car**
Glider Mass	kg	990
Frontal Area	m^2	2.1
Drag Coefficient		0.29
Wheel Radius	m	0.317
Rolling Resistance		0.008

Parameter	Unit	Value
0–60mph	s	9 +/- 0.1
0–30mph	s	3
Grade at 60 mph	%	6
Maximum Speed	mph	> 100 (1)

(1) Two gear transmission used for series

Fuel Cell System Assumptions

Parameter	Unit	Current Status	FreedomCAR Goal
Specific Power	W/kg	500	650
Peak Efficiency	%	55	60



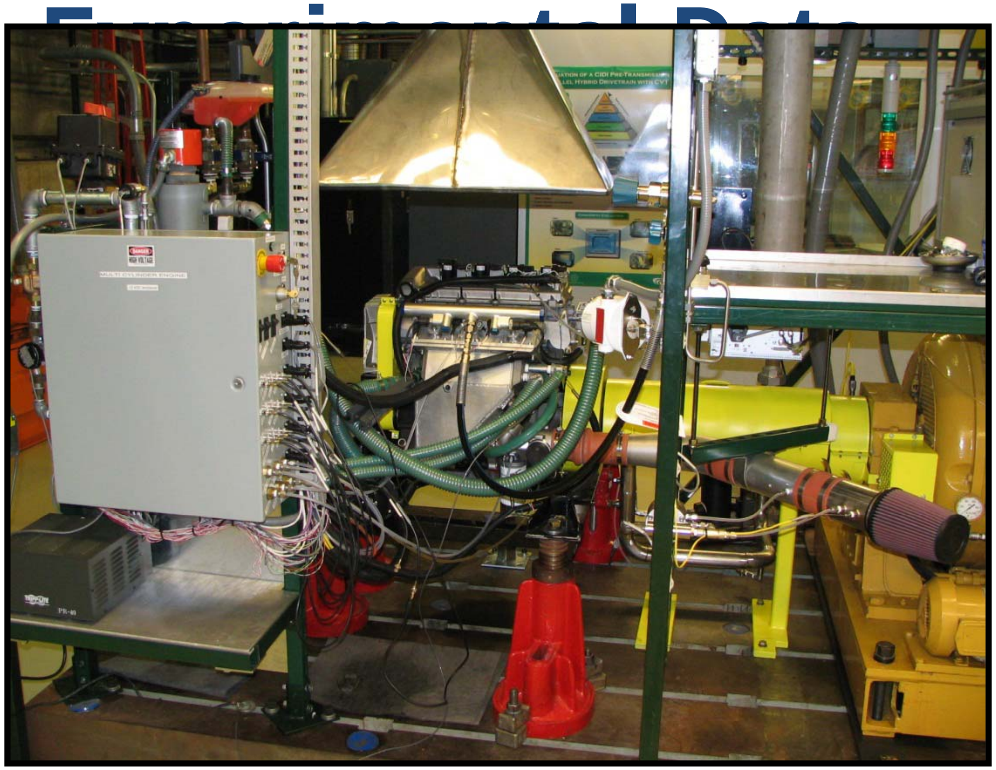
Without CEM

With Compressor Expander Module (CEM)

Model Limitation:

The efficiency curves used are steady-state, underestimating the parasitic load, which is much higher in real-world driving because of transient and non optimum control

Hydrogen Engine Characteristics for Current Technology Generated from Experimental Data

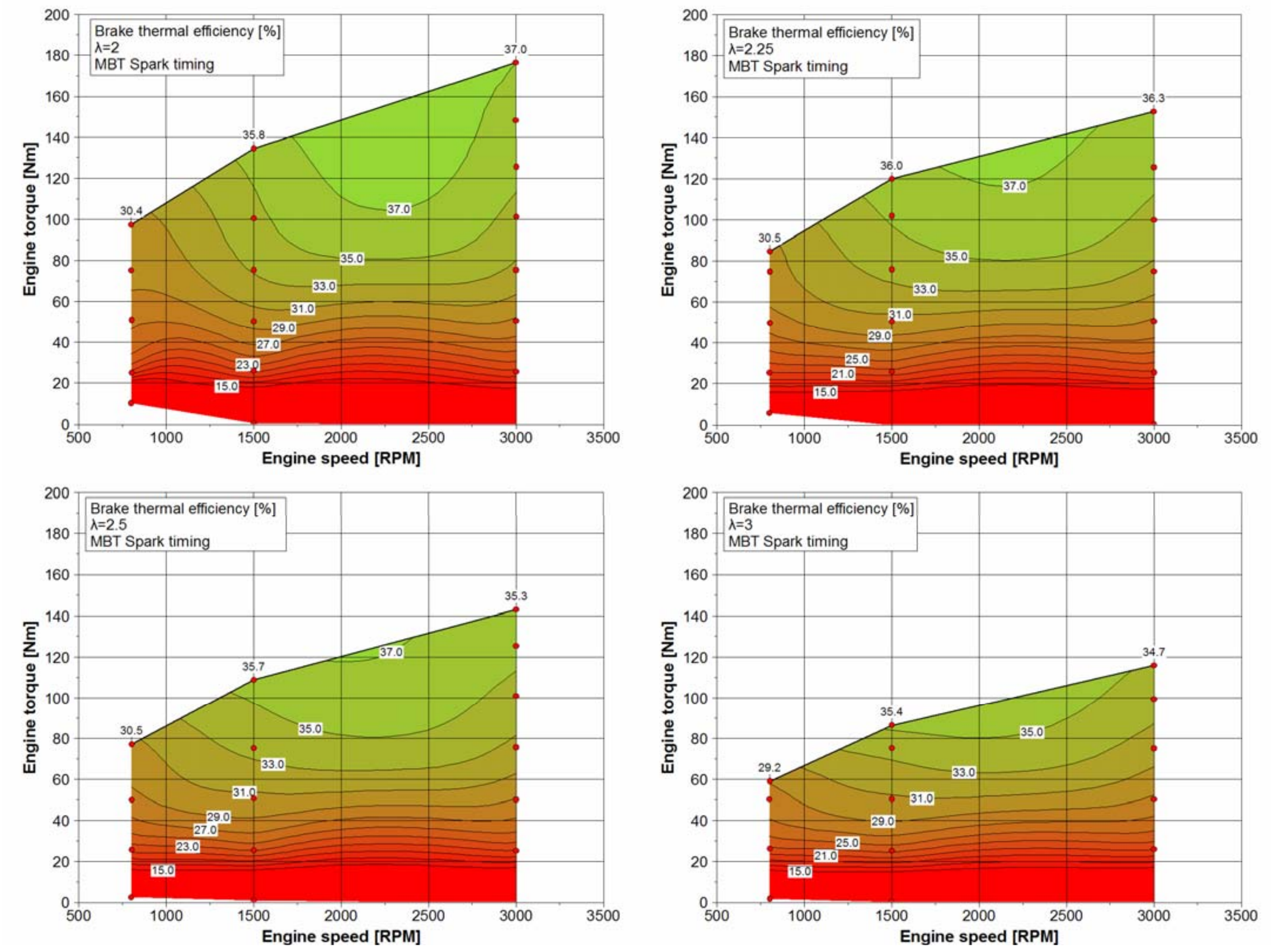


4-cylinder hydrogen engine setup

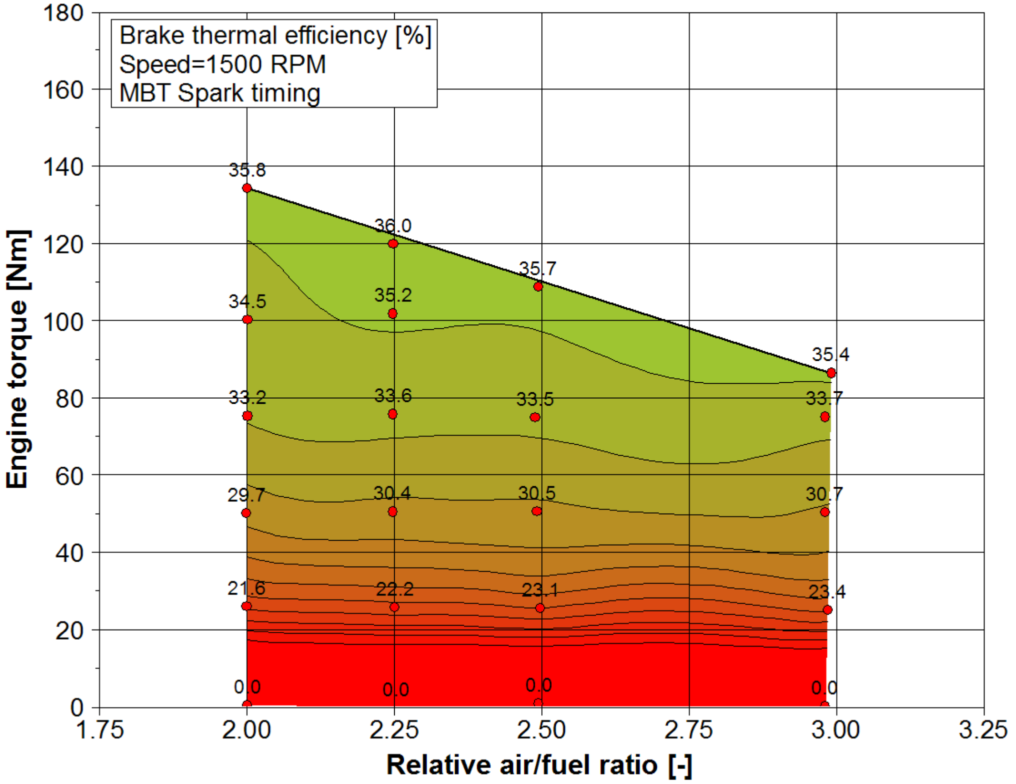
Manufacturer	Ford Motor Co.
Model	2.3L Duratec
Cylinders	4
Bore	87.5 mm
Stroke	94 mm
Compression ratio	12
Valve train	4V DOHC
Speed range	6000 RPM

- Modifications
  - Supercharger and intercooler
  - Hydrogen port fuel injection
  - After-market ECU

Port Injected Maps Generated for Different Air/Fuel Ratios

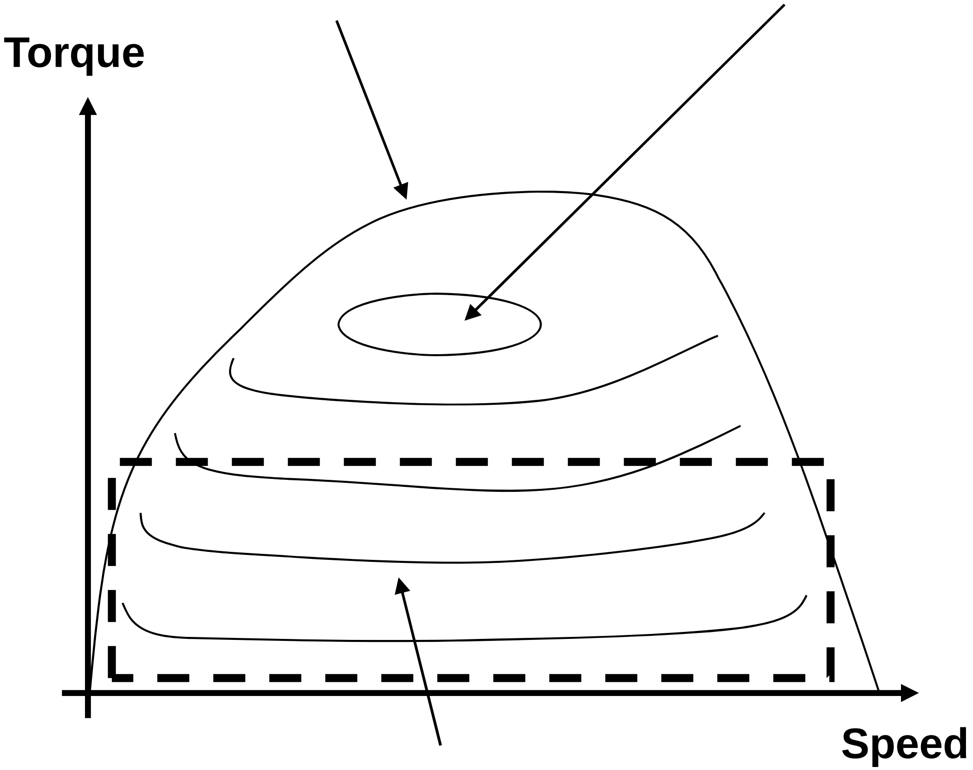


Final Port Injected Map Generated To Maximize Brake Thermal Efficiency



- Brake thermal efficiency increases with increased air/fuel ratio
- Maximum torque decreases with increased air/fuel ratio
- Due to lean operation peak efficiency is achieved at full load

Direct Injection Hydrogen Engine Operation Estimated from Single Cylinder Test Data



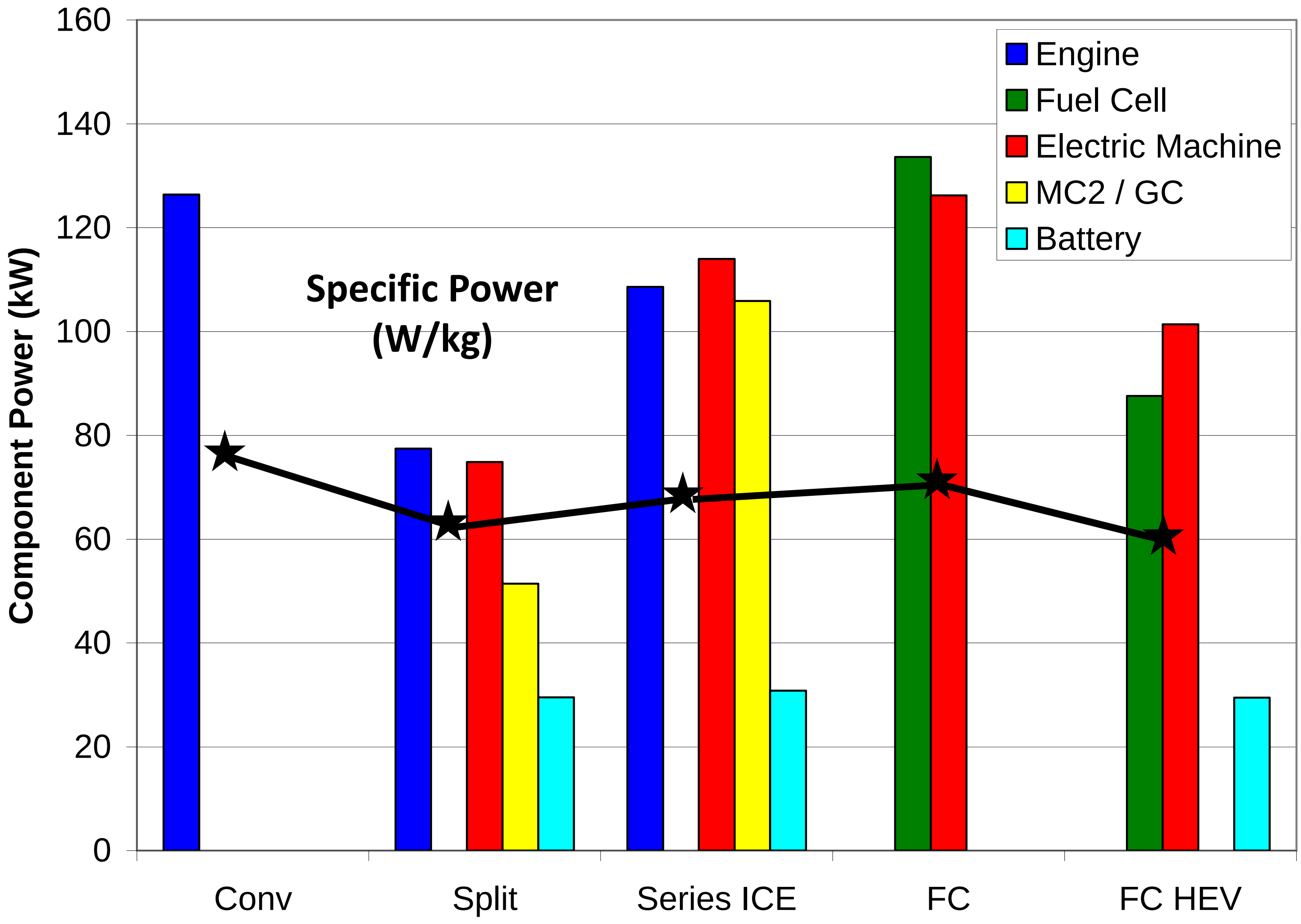
DI results in increased peak torque

Increased compression ratio & turbo charging

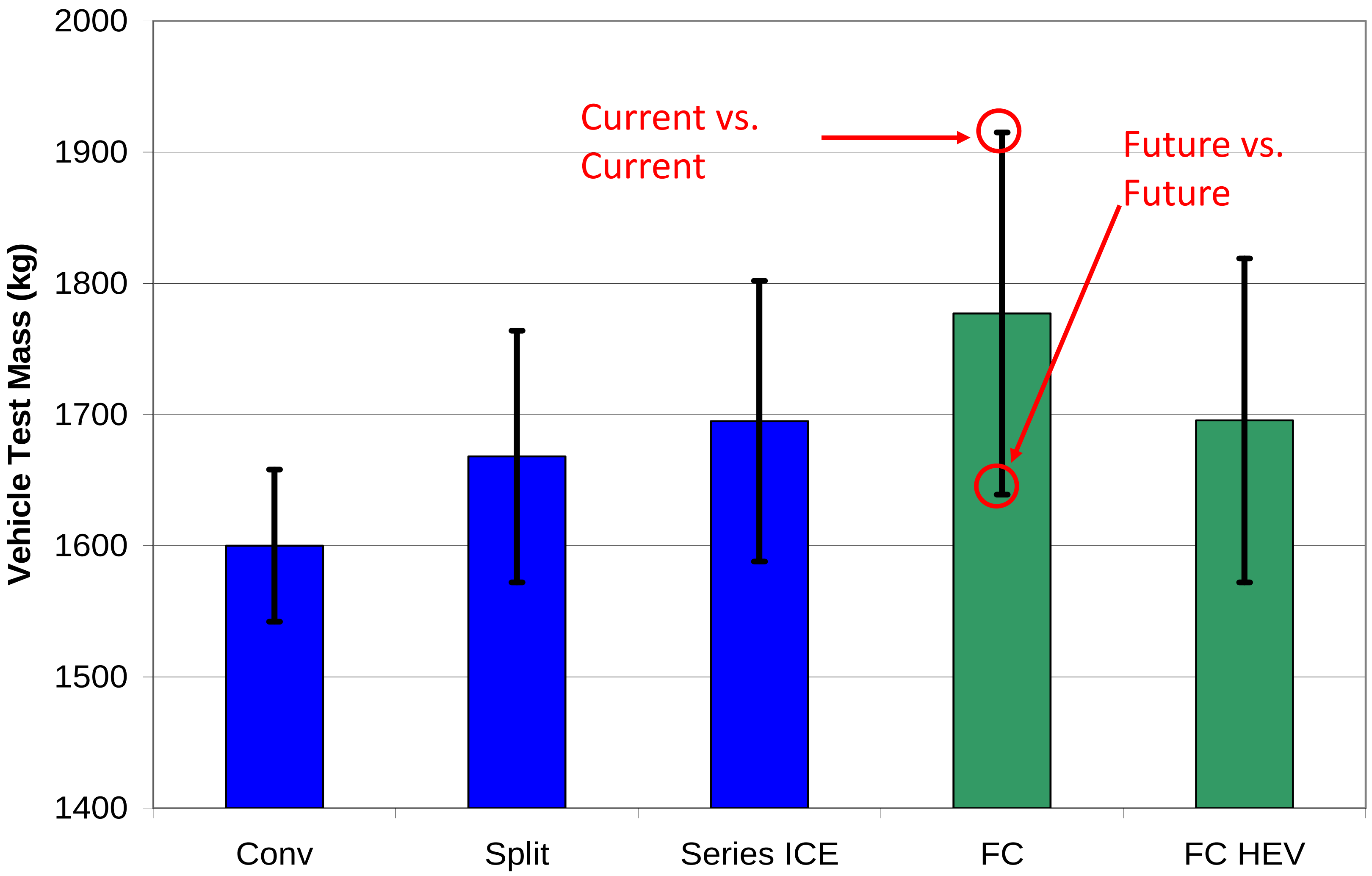
Lean part load

- Hydrogen Direct Injection will increase the peak torque curve
- Increased compression ratio will result in an increase in engine efficiency
- Turbo-charging will increase the engine efficiency compared to supercharging
- Lean part load operation will result in a further part load efficiency increase compared to throttled operation

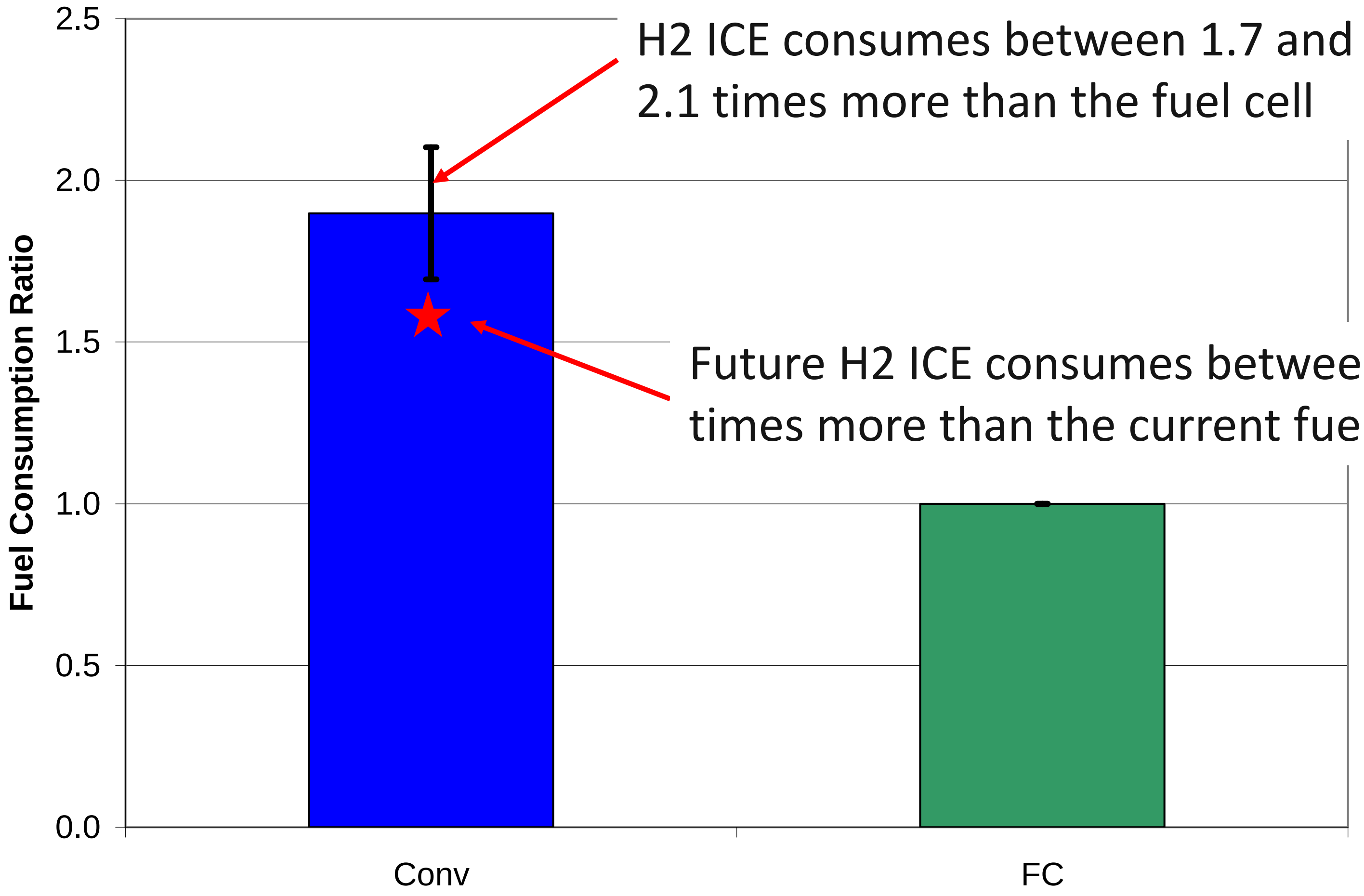
Component Average Power



Vehicle Mass



Non-Hybrid Configurations Comparison

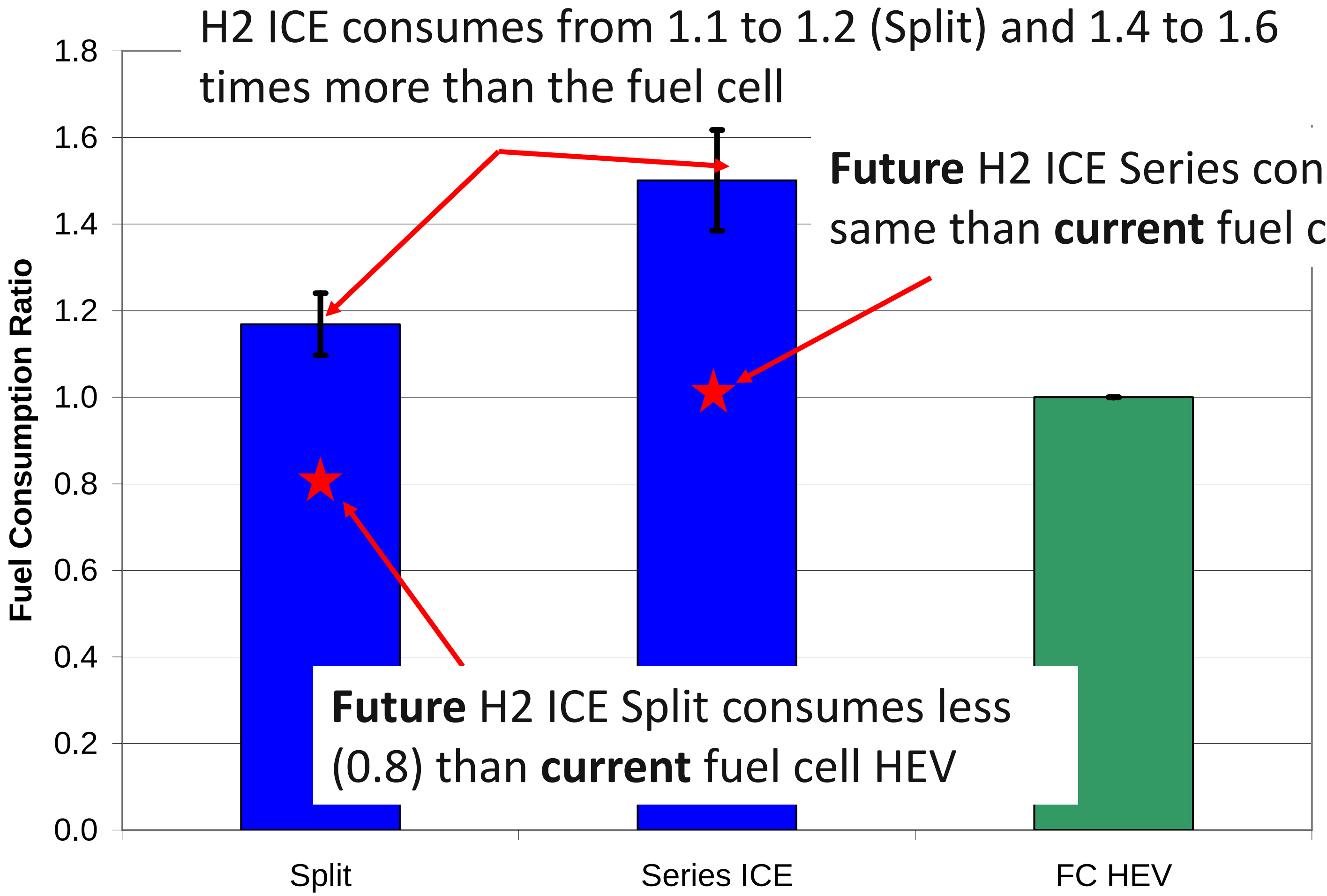


H2 ICE consumes between 1.7 and 2.1 times more than the fuel cell

Future H2 ICE consumes between 1.6 times more than the current fuel cell

Current vs. current -> H2 ICE will consume 1.7 more than fuel cell
Future vs. future -> H2 ICE will consume 2.1 more than fuel cell
Current fuel cell vs. future ICE -> H2 ICE will consume 1.57 more than fuel cell

Hybrid Configurations Comparison



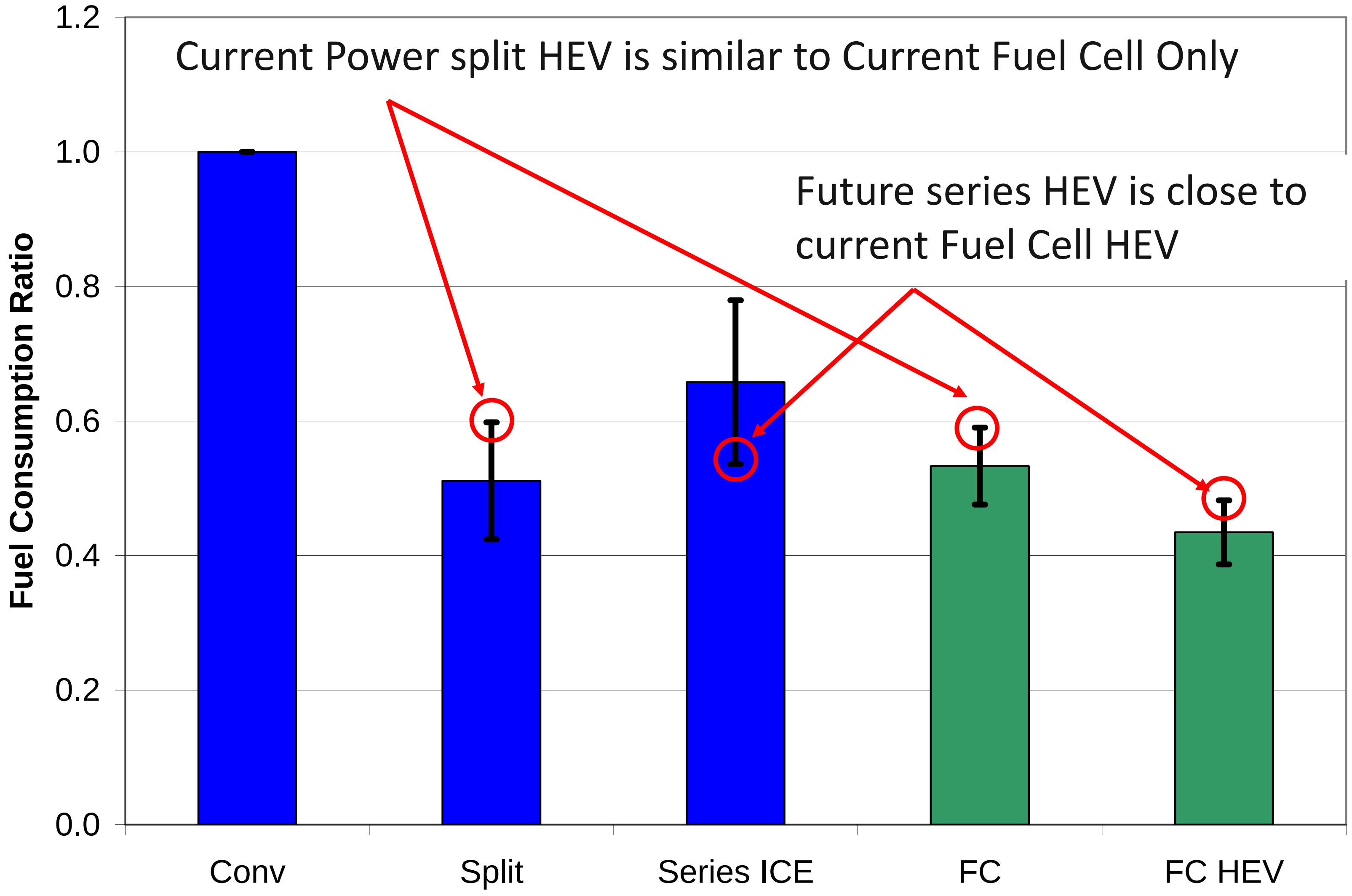
H2 ICE consumes from 1.1 to 1.2 (Split) and 1.4 to 1.6 times more than the fuel cell

Future H2 ICE Series consumes the same than **current** fuel cell HEV

Future H2 ICE Split consumes less (0.8) than **current** fuel cell HEV

Current vs. current -> H2 ICE Split will consume 1.24 more than fuel cell
Future vs. future -> H2 ICE Split will consume 1.1 more than fuel cell
Current fuel cell vs. future ICE -> H2 ICE Split will consume **<u>0.8 less</u>** than fuel cell

All Configurations Comparison



Current Power split HEV is similar to Current Fuel Cell Only

Future series HEV is close to current Fuel Cell HEV

Fuel Economy Results Analysis

- All HEVs configuration capture similar amount of energy at the wheel during deceleration (~98% on UDDS). However, the series configurations have more losses due to lower electric machine efficiencies than the power split.
- Both HEV configurations using ICE have similar average efficiencies (~31% for port injected and ~41.5% for direct injection on UDDS).
- The fuel cell system average efficiency remains higher (~47% for current case and ~51% for future case on UDDS).
- In addition, the series configuration with H2-ICE is penalized by the driveline inefficiencies (both generator ~90% and electric machine ~81%)

Conclusion

- The DI H2-ICE has been defined based on a combination of four-cylinder and single cylinder data generated for different A/F ratios.
- H2-ICE powertrain should be hybridized to be competitive with fuel cell systems vehicle fuel consumption.
- Power split configuration offers the best fuel consumption when using H2-ICE due to added inefficiencies in the series configuration.
- If one considers that the current fuel cell system efficiencies will remain constant in the future (most research is focused on cost and durability), DI H2-ICE could provide an interesting option (up to 20% reduction in fuel consumption).
- If one considers both future technologies within an HEV, a 10 to 40% increase in fuel consumption is noticed when using H2-ICE.